REPORT OF HYDRAULIC LABORATORY FILTER TESTS FOR CORDELL PUMPING PLANT - OROVILLE-TONASKET UNIT - CHIEF JOSEPH DAM PROJECT, WASHINGTON

AUGUST, 1979

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Memorandum
Chief, Water Conveyance Branch

Denver, Colorado
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Report on Hydraulic Laboratory Filter Tests for Cordell Pumping Plant - Oroville-Tonasket Unit - Chief Joseph Dam Project, Washington

SUMMARY AND CONCLUSIONS

A filter bed, located in a river bottom, has been proposed for a pump intake. Filtration and backwashing (reverse flow) tests were made for the upper portion of the filter bed. These tests were made in a plastic box where sediment movement could be observed through the transparent sides of the box. The box, an existing facility adapted for this test, provided an economic and simplistic test environment; riverflow across the filter bed was not simulated. Five filter configurations were tested and results are given in table 1. Following are conclusions from the tests:

1. A 2.4- to 4.8-mm-diameter (No. 8 to No. 4 sieve size) sand was too coarse and did not filter the sediment.

2. A 1.2- to 2.4-mm-diameter (No. 16 to No. 8 sieve size) sand provided good filtration.

3. A 150-mm (6-in) thick layer of filter sand was adequate.

4. The sediment itself helped filtration. Fine sand from the sediment was trapped on top of the filter sand and provided a finer particle filter medium.

5. With respect to backwashing, two filtration schemes worked successfully in the test apparatus. The first scheme was fluidization of the filter sand and the second was placement of a gravel layer over the filter sand. However, both schemes have drawbacks. With the first scheme, a cover must be developed to protect the filter sand against erosion from the river currents. The second requires a larger backwashing discharge than scheme one and may require an expensive underpiping system beneath the filter bed.

6. Further testing is required in a more elaborate facility. The condition of riverflow passing over the filter bed must be simulated. This type study requires a flume with a sediment pump for recirculating the water and sediment past the filter and some means of measuring

sediment concentration. Cost of the future study is estimated in the range of $75,000.

7. Although the present study did not provide a definite answer, it zeroed in on two feasible directions of future study and provided guidance on which filter bed sands and gravels to use. Additionally, the initial study allowed a decision point before expending funds for a larger, more complex study.

INTRODUCTION

A filter bed installed in the river bottom was proposed for a pump intake, the purpose being to exclude fine sediment that would cause excessive wear on pumps and irrigation sprinkler heads. This concept is being considered for the design of the Cordell Pumping Plant, Oroville-Tonasket Unit, Chief Joseph Dam Project, Washington.

The designers had obtained a computerized literature search that did not furnish enough information for designing a filter bed in a river bottom with assurance of good operation. Design information was needed about (1) size of filter sand and thickness of the filter bed that would provide the desired fine sediment filtration, (2) filter bed discharge and head loss, and (3) a satisfactory backwashing capability for flushing out fine sediment and rejuvenating the filter. A laboratory study was started in an effort to obtain the desired information.

TEST PROGRAM OBJECTIVE

Before the piping system beneath the filter bed could be designed, the flow properties for a unit area of the filter bed were needed. Thus, the laboratory study was directed toward obtaining a feasible answer for the filtration portion of the filter bed.

Criteria for the filter was established during meetings of design and research personnel. The filter should exclude larger than 0.075-mm-diameter (No. 200 sieve size) sediment. The maximum filtration discharge for operation would be 6 $L/m^2 \cdot s$ (15 gal/min per ft^2). A minimum discharge for the filter would be 3.3 $L/m^2 \cdot s$ (5 gal/min per ft^2) with less than 3-m (10-ft) head loss; however, the filter would probably be backwashed before reaching a head loss this large.

With respect to backwashing, two filtration schemes were considered. One scheme was fluidizing the filter sand and the second scheme was placing a gravel layer over the filter sand. Fluidizing is a method commonly used for cleaning sand filters. Water is pumped in the reverse direction through the filter, with sufficient flow to partially suspend the sand grains. A boiling sand movement occurs within the filter bed and the upward flowing water can better flush out the fine sediment. However, if fluidizing is used, a structural cover would be needed over the filter bed to prevent erosion of the filter sand by the river current. With the second scheme, a gravel layer protects the filter sand from river erosion, but may inhibit the backwashing cleaning action.

THE TEST APPARATUS

The test apparatus is shown in figure 1. A plastic box 300-mm wide, 600-mm long, and 1800-mm deep (1- by 2- by 6-ft) was elevated on a platform. Piping, valves, and a pump provided water entry at either the top or bottom of the plastic box.

Various gravel and sand layers were placed in the box. Under the filter sand, it is desirable to have minimal head loss. A very pervious gravel should be placed around piping beneath the filter bed. Intermediate size gravel layers are placed beneath the filter sand to prevent movement of the smaller particles between voids of the larger particles. In the test box, the bottom gravel layer rested on a plate that had a grid of thirty-six 6.4-mm (1/4-in) diameter holes, providing an even distribution of waterflow through the filter. Head loss measurements were made with piezometer taps (fig. 1 and 2) that were connected to a manometer board.

When operating in the filtration mode, water was pumped to the top of the plastic box. A nearly constant water surface elevation was maintained by allowing some water to pass through the overflow weir. When operating in the backflushing mode, water was pumped to the bottom of the plastic box, flowed upward through the filter, and out through the overflow weir. In either mode of operation, discharge was controlled by opening and closing the appropriate valves. Discharge rate was obtained by weighing the water collected in a container during a measured time interval. The water system was self-contained whereby water was pumped from and returned to a storage box.

THE TESTS

Five different filter configurations were tested (fig. 3). Discharge-head loss measurements were made for each filter configuration when in a clean condition. Filtration head loss data are shown on figure 4 and backwashing head loss data on figure 5.

For the sedimentation tests, 0.5 L (30 in^3) of dry sediment was poured into the top of the plastic box and allowed to settle during a 5- to 20-minute period before adding the next 0.5 L (30 in^3) of sediment. Passage of sediment through the filter was checked by screening the discharge through a nylon cloth (plankton netting) that had 0.10-mm (0.004-in) openings. After the sedimentation test, a backwashing test was performed and a judgment made about the discharge needed for flushing sediment from the filter. Pertinent test data for the five filter configurations are given in table 1.

Filter configuration No. 1. - The filter medium was a 300-mm-thick (12-in) layer of 2.4- to 4.8-mm-diameter (No. 8 to No. 4 sieve size) sand, figure 3. This was the largest size filter sand considered, and the objective was to obtain the lowest head loss. However, the sand could not be fluidized, even with 34-L/m^2·s (50-gal/min per ft^2) reverse flow. During the sedimentation test, there was a 50-percent increase in head loss and sediment passed through the filter. During backwashing, a large portion of the sediment was removed from the plastic box. The filter sand was washed clean and sediment that previously had been filtered out on top of the sand was placed in suspension. Upward velocity of the water was greater than settling velocity of the smaller sediment particles, moving these particles upward to the overflow weir. The larger size sediment particles were moved only 100-mm (4-in) above the filter bed and were in a fluidized state. When the backwashing was stopped, the large particles immediately settled onto the sand filter bed.

The 2.4- to 4.8-mm-diameter (No. 8 to No. 4 sieve size) sand particles were too large and did not provide the desired filtration. A smaller size filter sand was needed.

Filter configuration No. 2. - Filter sand of the previous configuration was removed and replaced with a 300-mm-thick (12-in) layer of 1.2- to 2.4-mm-diameter (No. 16 to No. 8 sieve size) sand. The sand was placed in a dry condition and tamped with a block of wood. During the first backwashing test, the sand fluidized. Filtration and backwashing data are designated 2A on figures 4 and 5. After turning the discharge off, the sand was less compacted and was about 20 mm above the 300-mm mark. The excess sand was removed and tests made again. There was less head loss with the second test (2B of fig. 4 and 5). Thereafter, the sand was not compacted when placed in the plastic box.

During the sedimentation test, 5.5 L (335 in^3) of sediment were added. Visual observations through the plastic sides of the box showed the sediment was trapped on top of the filter sand. No appreciable sediment from the filter discharge was caught in the nylon netting. The head loss for the sand layer increased to 2.1 m (7 ft), while the filter discharge decreased from 10 to 7 L/m^2·s (from 15 to 10 gal/min per ft^2). Manometer readings indicated the increased head loss occurred through the fine sediment layer deposited on the filter sand.

Filter configuration No. 3. - For the prevous configuration, the filter sand would be exposed to the river currents. A gravel layer over the filter sand could provide protection against erosion. In configuration No. 3, a 200-mm (8-in) thick gravel layer was tested, figure 3. A 75-mm (3-in) fine gravel layer was placed between the gravel and filter sand to prevent movement of the filter sand into the gravel. In the initial clean test condition, the filtering head loss was found similar to configuration No. 2, and only one test point was obtained (fig. 4). Visual observations were made for backwashing and data taken for the maximum discharge (3A of fig. 5).

During the first sedimentation test, 4.5 L of sediment were added. Some of the sediment settled on top of the gravel particles, but most passed through the 200-mm-thick gravel layer and 75-mm-thick fine gravel layer and deposited on top of the filter sand. The deposit increased in thickness, almost completely filling the 75-mm-thick gravel layer. The head loss increased to 2.9 m (9.6 ft) and the discharge decreased to 4 $L/m^2 \cdot s$ (6.5 gal/min per ft^2).

An 18 $L/m^2 \cdot s$ (26.1 gal/min per ft^2) discharge was used for backwashing (3B of fig. 5). Almost all the sediment was flushed from the upper surface of the filter sand and the 75-mm-thick (3-in) fine gravel layer was completely cleaned. However, not all the sediment was flushed from the 200-mm-thick (8-in) gravel layer. The large size sediment particles circulated within the gravel bed. High velocity flow areas between rocks would move particles upward, then the particles would contact sheltered flow areas behind rocks and settle downward. Above the gravel layer, the sediment particles were in a suspended or fluidized state. These particles were suspended by the relatively higher velocity jets exiting from the gravel voids, but above the gravel bed, the velocity dissipated and the particles settled. If the river current was flowing over the gravel, these particles would probably have been carried downstream. Smaller size sediment particles were flushed from the plastic box. After the backwashing was stopped, much of the sediment settled downward through the large and fine gravel and came to rest on top of the filter sand.

A second sedimentation test was made, and after adding sediment, the filter operation was continued for 3 hours. Air accumulated in the filter sand beneath the sediment layer. The presence of air was shown by an area of lighter color which formed beneath the sediment layer and increased in thickness. Filter operation was stopped at the end of the day and restarted the next morning. Air accumulation continued with a lowering of the colored area. After 2 hours, the air accumulation lowered to the large size gravel at the bottom of the plastic box, and a distinct water level was observed in the gravel. Filtration was stopped and backwashing started; air bubbles came out of the filter bed. Better backwashing was desired and a discharge greater than the previous backwashing discharge was used. A horizontal crack formed in the bottom part of the filter sand, the crack opening increased in size, and the filter bed above the crack raised. When the discharge was turned off, the crack closed and the bed settled down. By appropriate opening and closing of the valve, the cycle of crack opening and closure was repeated. However, the valve was not opened too much or too large a crack allowed to form because of the potential danger of rupturing the filter bed. Sometimes, when the bed was resettling, bubbles of air escaped from the filter sand, indicating that not all the air could be purged from the filter sand when backwashing. Afterwards, a series of backwashing measurments were taken (3C of fig. 5).

A third sedimentation test was made and backwashing data taken (3D of fig. 5). Discharge-head loss test results were different between 3A, 3B, 3C, and 3D of figure 5. Whether because of air or disturbances to the filter bed by raising and lowering of the bed during backwashing, the flow resistance had changed. A backwashing discharge of 20 $L/m^2 \cdot s$ (29.4 gal/min per ft^2) was used and provided better flushing of sediment.

Two explanations are proposed for accumulation of air in the filter bed. The first is that dissolved air was coming out of solution. Circulation and pumping of the water allowed for complete saturation. As the water passed through the deposited sediment layer, a drop in pressure occurred because of the head loss. This low-pressure region provided a supersaturated environment for the water and encouraged air to come out of solution. The second explanation is the presence of minute air bubbles in the water. Water entered at the top of the plastic box by a weir-type fow. Bubbles were generated and the larger bubbles moved upward to the water surface. However, the smaller bubbles moved more readily with water currents in the box, and when traveling downward, were compressed and decreased in size. When passing into the lower pressure region, the minute bubbles could expand and collect beneath the sediment layer. These minute bubbles at and near the filter bed were seen by shining a high-power photographic light through the plastic box. Of the two explanations, the minute air bubbles offer the most potential for air accumulation that occurred in the tests. However, the first explanation was mentioned because it may be possible for air to come out of solution at a filter bed in the field. If required backwashing discharges are too large, there is danger the filter bed may be ruptured. This danger should not inadvertently be overlooked in future considerations of a filter bed with a protective gravel covering.

Test observations for configuration No. 3 influenced three changes that were made for the next filter configuration.

1. The fine gravel layer on top of the filter sand was inadequate. During backwashing, some filter sand passed through the gravel. A smaller size particle was needed for this layer.

2. Filtering of the sediment occurred on top of the sand filter. During the sedimentation tests, the head loss increased between

piezometers No. 7 and 8 and decreased between piezometers No. 4 and 5, 5 and 6, and 6 and 7. Thus, the sigificant head loss occurred through the deposited sediment layer and not through the 300-mm (12-in) depth of filter sand. A 150-mm (6-in) depth of filter sand should be sufficient and provide less flow resistance when backwashing. Hopefully, more backwashing discharge could pass through the filter layer without danger of rupturing the filter bed.

3. During backwashing, the fine gravel layer on top of the filter sand was washed clean, but the protective layer of large size gravel had considerable sediment circulating within the layer. Presumably, voids between the large gravel were too large, and flow velocities were slower than those of the fine gravel. The next gravel layer would have one-third part of fine gravel and two-thirds parts of large gravel; the intent being to make smaller void spaces within the protective gravel and have better cleaning action.

Filter configuration No. 4. - The filter medium was 150 mm (6 in) thick and had upper sand and gravel layers as shown in figure 3. Clean condition head losses were measured (No. 4 of fig. 4 and 4A of fig. 5). These head losses were somewhat less than configuration No. 3. During the sedimentation test, 6.5 L (396 in^3) of sediment were added. The filtration discharge decreased from 10 to 4 $L/m^2 \cdot s$ (14.8 to 5.9 gal/min per ft^2) and the head loss increased from 0.09 to 3.08 m (0.26 to 10.11 ft). When backwashing (4B of fig. 5), the head loss had increased from that of the clean condition. Difficulties of air accumulation within the filter bed were also experienced during this test.

The coarse sand layer on top of the filter sand had adequate particle size; the filter sand did not pass through this layer when backwashing. Also, the gravel mixture of the protective layer was believed better for backwashing. A slightly smaller backwashing discharge appeared to give similar results to those of configuration No. 3.

Filter configuration No. 5. - The objective of configuration No. 5 was to provide a smaller backwashing discharge, thus a finer filter sand was used. The filter medium was a 150-mm (6-in) thick layer of 0.6 to 1.2-mm-diameter sand (No. 30 to No. 16 sieve size) (fig. 3). Because of the finer filter sand, another sublayer of intermediate size sand was needed to prevent the filter sand from moving into the lower gravel layers. Two sedimentation tests were made; for the first test, 0.5 L (30 in^3) of sediment was added, and for the second test, 4 L (244 in^3) of sediment were added. There was more head loss in the first test than the second. The accumulation of air within the filter was believed to have caused the conflicting test results. When backwashing, a 12-$L/m^2 \cdot s$ (17.5 gal/min per ft^2) discharge provided good fluidizing action of the filter sand. The larger particles of sediment were fluidized and were located immediately above the filter sand. The fine sediment was washed from the box. This filter configuration had the lowest backwashing discharge (table 1).

THE FLUIDIZATION PROCESS

When sufficient water is forced upward through the sand medium, fluidization can occur. The sand grains are no longer resting firmly against each other since the force of the flowing water separates the grains. Depending upon the backwashing discharge and sand size, difference modes of sand movement were observed through the sides of the plastic box. With the larger filter sand and initial fluidization, only piping and slight boiling at random locations were observed. An increased discharge produced more pronounced upward boiling of the sand grains and at more locations. As the sand moved upward, sand in an adjacent area would be settling downward and feeding the upward boil. A further increase of discharge produced faster sand movement and less discernible patterns of the upward and downward cells of sand movement. With the finer sand, a similar mode of movement was observed, except at the higher discharges where the sand appeared somewhat in a state of continuous suspension.

Darcy's law is a formula that considers porous media flow resistance and can provide some insight about the fluidization process. Water flowing through the sand has a head loss, and there are different pressures at the top and bottom of the filter sand layer (fig. 6a and 6b). This difference creates an upward force acting upon the sand layer. As the backwashing discharge is increased, there is some point where the upward force (F) is equal to or slightly greater than the submerged weight (SW) of the sand. Then some dislodgement of the sand particles can occur with initial fluidization as described in the prevous paragraph. Further increases of the backwashing discharge produces better fluidization with increased separation of the sand particles and the sand bed expands (fig. 6c). Thus, separation allows easier water movement through the sand without appreciable increase of head loss (fig. 6d).

Data from the tests were similar to figure 6d (configurations No. 2 and 5, fig. 5). Another feature, to note from figure 6, is a smaller size sand will fluidize with a smaller backwashing discharge than a larger sand. A smaller sand has less permeability and greater flow resistance, thus producing more upward force.

DISCUSSION OF THE TESTS

Problems were encountered with sediment used for the tests. For filter configurations No. 1, 2, and 3, the sediment used was that of curve A (fig. 7). This sediment was selected on the basis of availability. Curves D and C of figure 7 show the limits of sediment desired for the tests. Curve A sediment had insufficient fines. Therefore, a request was made for field sediment to be shipped to the laboratory for tests, (curve B of fig. 7). This sediment (curve B) was also low for desired fines. Evidently, the fines had stayed in the riverflow and not deposited. Another sediment (curve E, fig. 7), may be helpful for future tests. By adding a size fraction between the No. 30 and No. 100 screens to sediment E, a better representation will be made for the suspended river sediment.

Initially, the tests were believed to give some indication about how long a prototype filter could operate before being backwashed. The rationale for this indication is as follows: A suspended sediment concentration of 300 mg/L would be assumed for the river. As water passed thrugh the filter, all of the suspended sediment would deposit. For each cubic meter of filtered water, there would be 300 g of sediment. 0.5 L of dry sediment in the laboratory tests had a mass of 680 g. Thus, by ratios of the sediment, 0.5 L of test sediment represented 2.27 m^3 of filtered river water. Considering the test filter area, the 0.5 L of sediment corresponded to 12.22 m^3 of water passing through 1 m^2 (300 gal/ft^2) of prototype filter. Knowing area of the filter and pumping rates, the prototype operation time could be computed. However, the test sediment lacked fines and was believed not to plug up the filter as much as the river sediment. In addition, the tests had trouble with air accumulation, which did plug up the filter. Therefore, the test results were not used for predicting operation time of the prototype filter.

The tests showed sand between 1.2 and 2.4 mm (No. 16 to No. 8 sieve size) in diameter provided good filtration. Although the filtered water passed through a 0.10-mm (0.004-in) opening mesh instead of a 0.075-mm (No. 200 screen) mesh, the filtering was judged good because of visual observations of water turbidity. At the beginning of a sedimentation test, the water was very turbid, but after operating had cleared considerably. The sediment itself improved filtering characteristics. Fine sand from the sediment was caught upon the filter sand, and the fine sand filtered smaller particles. Because of this fine sand, the depth of the filter sand can be much less than that of municipal water filters.

The tests indicated that the fluidizing filter scheme used less backwashing discharge than the filtering scheme with the protective gravel cover. Either scheme used considerably more backwashing discharge than filtration discharge. From a design standpoint, a backwashing discharge closer to the filtering discharge would be more favorable because of the piping system beneath the filter. In the backwashing mode, the pressure distribution under the sand filter bed must be uniform. If higher pressure areas exist, more water will flow through the sand and there is a danger of rupturing the bed.

Although sediment and air difficulties were encountered with the test apparatus, the test program successfully accomplished the intended objectives. The apparatus allowed an easy placement and removal of filter configurations and a faster testing time than if all the complexities of the filtration problem had been studied. Good filtration was obtained and backwashing was accomplished. However, backwashing appears to be the crux of the problem. Filter configurations No. 4 and 5 show promise of working and should be further studied in a more elaborate testing facility.

FUTURE TESTS

A test environment more similar to that of a river bottom is needed. The plastic box provided a somewhat static environment. When backwashing, the sediment could be flushed from the bed but immediately settled back into the bed after the discharge was turned off, whereas the river is a dynamic environment and backwashed sediment would be moved away from the bed. Thus, the laboratory filter bed needs to be placed in the bottom of a flume with flowing water and with suspended sediment in the water when making filtration tests.

Both the protective gravel cover and the filtration schemes should be studied. With the protective gravel scheme, many cycles of filtration and backwashing will be needed to investigate incomplete cleaning characteristics of the gravel. Can desired filtration and backwashing be accomplished if large size sediment particles remain in the gravel? With the fluidizing scheme, a cover needs to be developed to protect the filter sand from erosion by the river currents. A conceptual design of this cover is shown in figure 8a and intended backwashing operation in figure 8b. The louver-type arrangement could improve efficiency of the backwashing operation. Velocity above the fluidized bed would be increased and thus should better flush sediment from the filter and, hopefully, provide some cleaning action to the river side of the cover.

Another alternative for study would be a cover of porous material developed by the Polymer Concrete and Structural Section. A polymer liquid material is mixed with aggregate and binds the aggregate together. Yet many pores remain allowing the passage of water. Probably if this material did work, the cover would act as the filter. Tests would investigate whether the desired filtration was obtained and whether the filter would plug.

Hydraulic Laboratory studies with recirculating sediment flows are costly. An estimated cost for the future study is in the range of $75,000.

D. L. King
for CR3

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D-272 (Anderson
D-1530

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Table 1. - Filtration and backwashing test results for the five filter configurations

Configuration	Filtration head loss (clean bed) mm (ft)	Required backwashing discharge $L/m^2 \cdot s$ (gal/min per ft^2)	Backwashing discharge head loss mm (ft)
*1	40 (0.12)	Could not fluidize	
*2	130 (0.43)	25 (36.6)	250 (0.83)
**3	130 (0.43)	20 (29.4)	500 (1.65)
**4	100 (0.34)	18 (26.4)	540 (1.76)
*5	190 (0.61)	12 (17.5)	120 (0.41)

* Fluidizing configuration.
** Protective gravel covering over sand filter layer.

<u>Note</u>:

(1) Filtration head loss was for a 10-$L/m^2 \cdot s$ (15-gal/min per ft^2) discharge.

(2) Head losses for both filtration and backwashing are from the bottom of the sand filter layer to the top of the filter bed.

Figure la - Plastic box on platform, piping and storage box in the foreground.

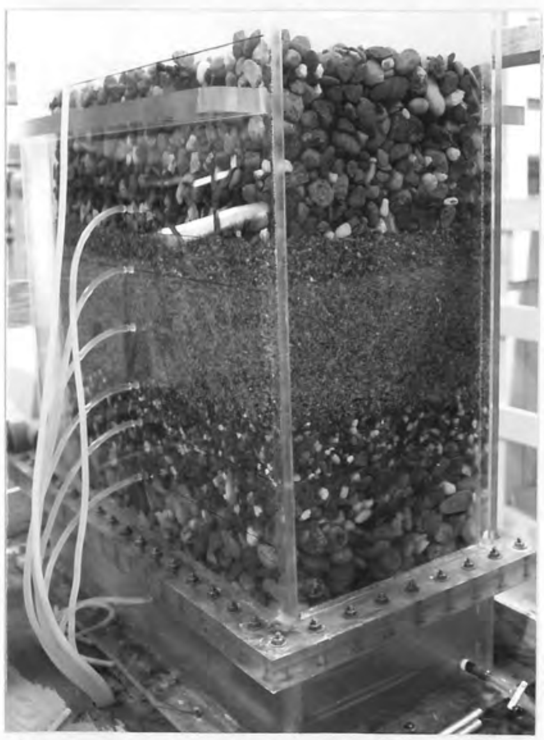


Figure lb - Filter configuration #4 in plastic box.

Figure 1 - The test facility.

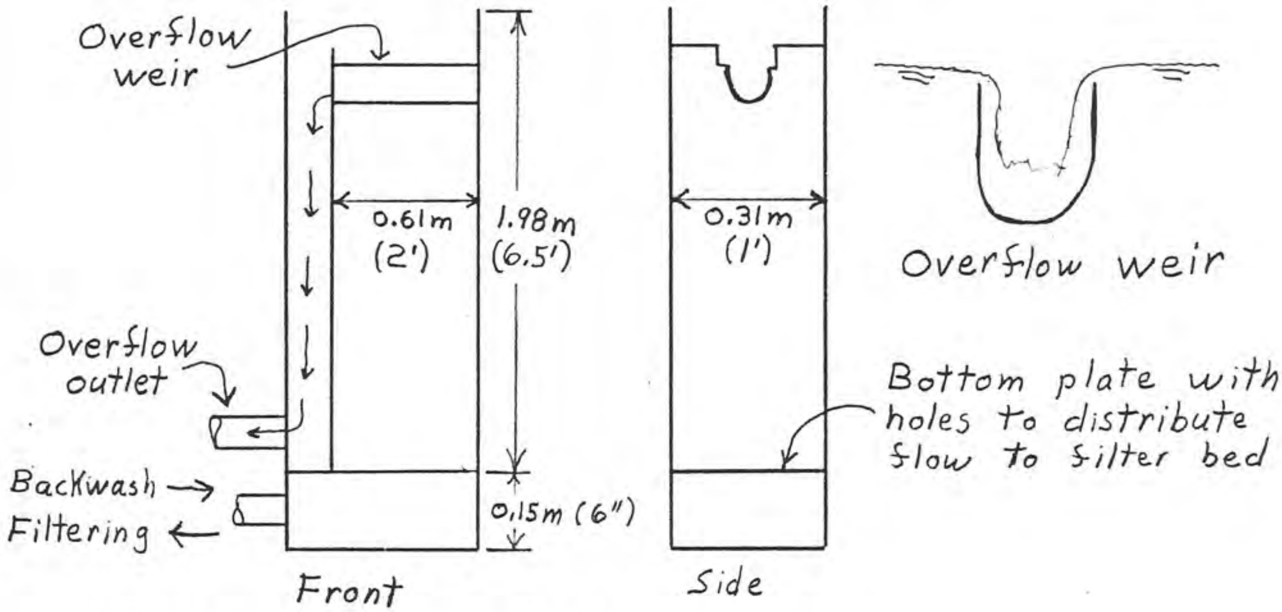


Figure 2a - General dimensions.

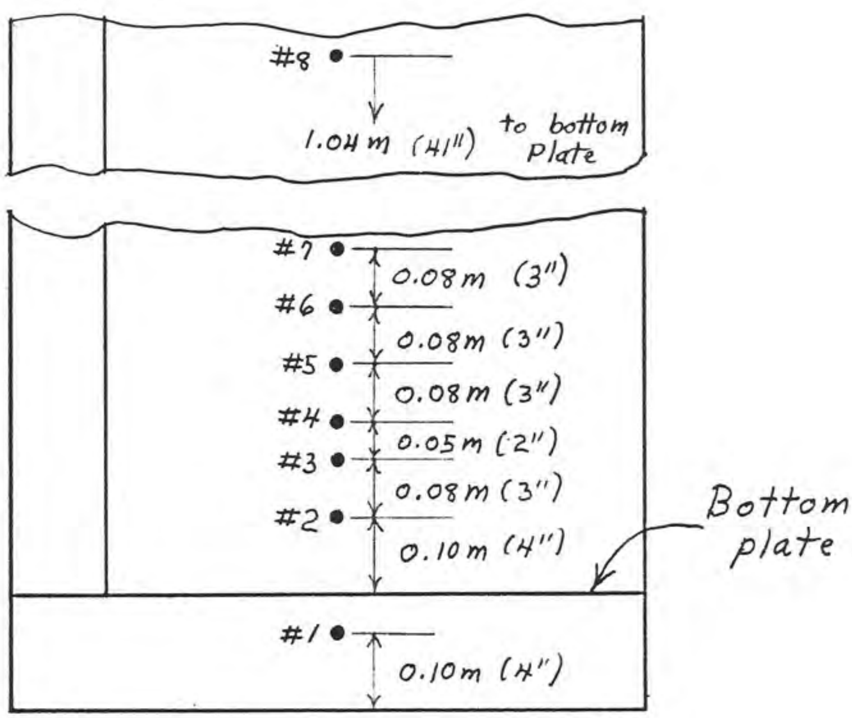
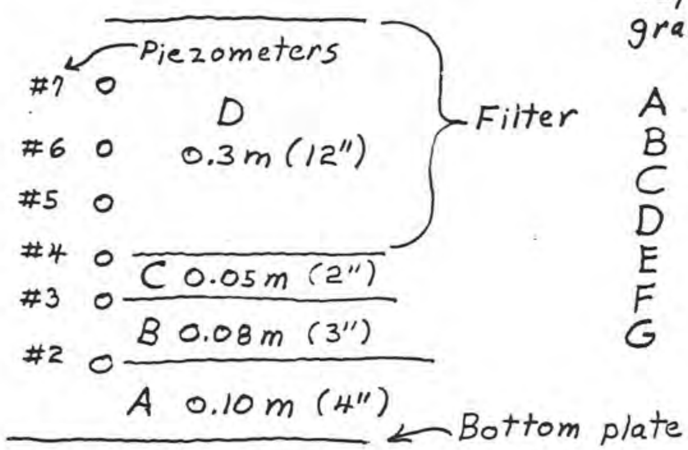


Figure 2b - Location of piezometer taps.

Figure 2. Plastic box dimensions.

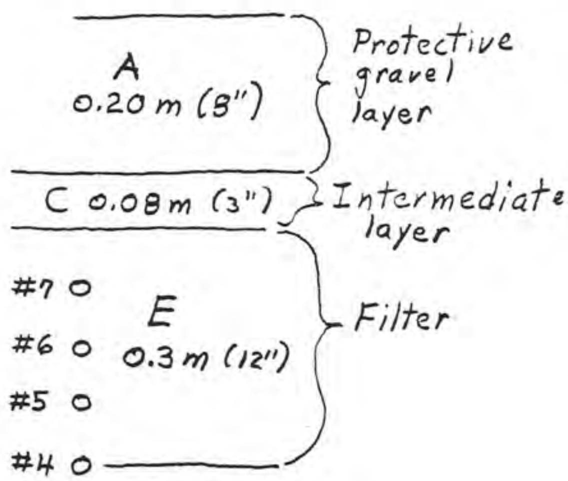


Key for sieved sand and gravel – see figure 7.

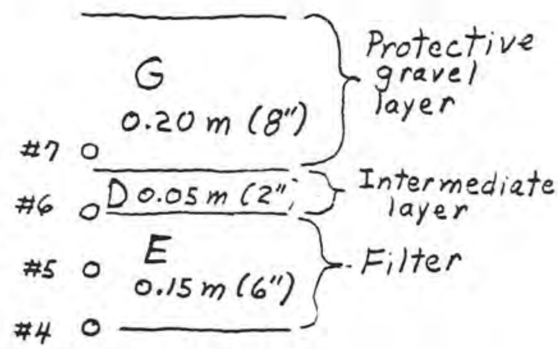
A	19 to 38 mm
B	9.5 to 19 mm
C	4.8 to 9.5 mm
D	2.4 to 4.8 mm
E	1.2 to 2.4 mm
F	0.6 to 1.2 mm
G	Gravel mixture 1/3 B and 2/3 A

Configuration #1 – A, B, C, and D are layers of gravel and sand that were used for filter configuration #1, and thickness of the layer is given by the following numbers. For the following configurations no changes were made for layers A, B, and C.

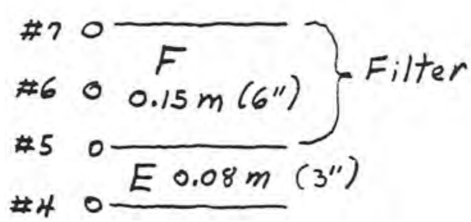
Configuration #2 – Same as #1, except filter layer was replaced with "E" sand.



Configuration #3



Configuration #4



Configuration #5

Figure 3. Filter configurations that were tested.

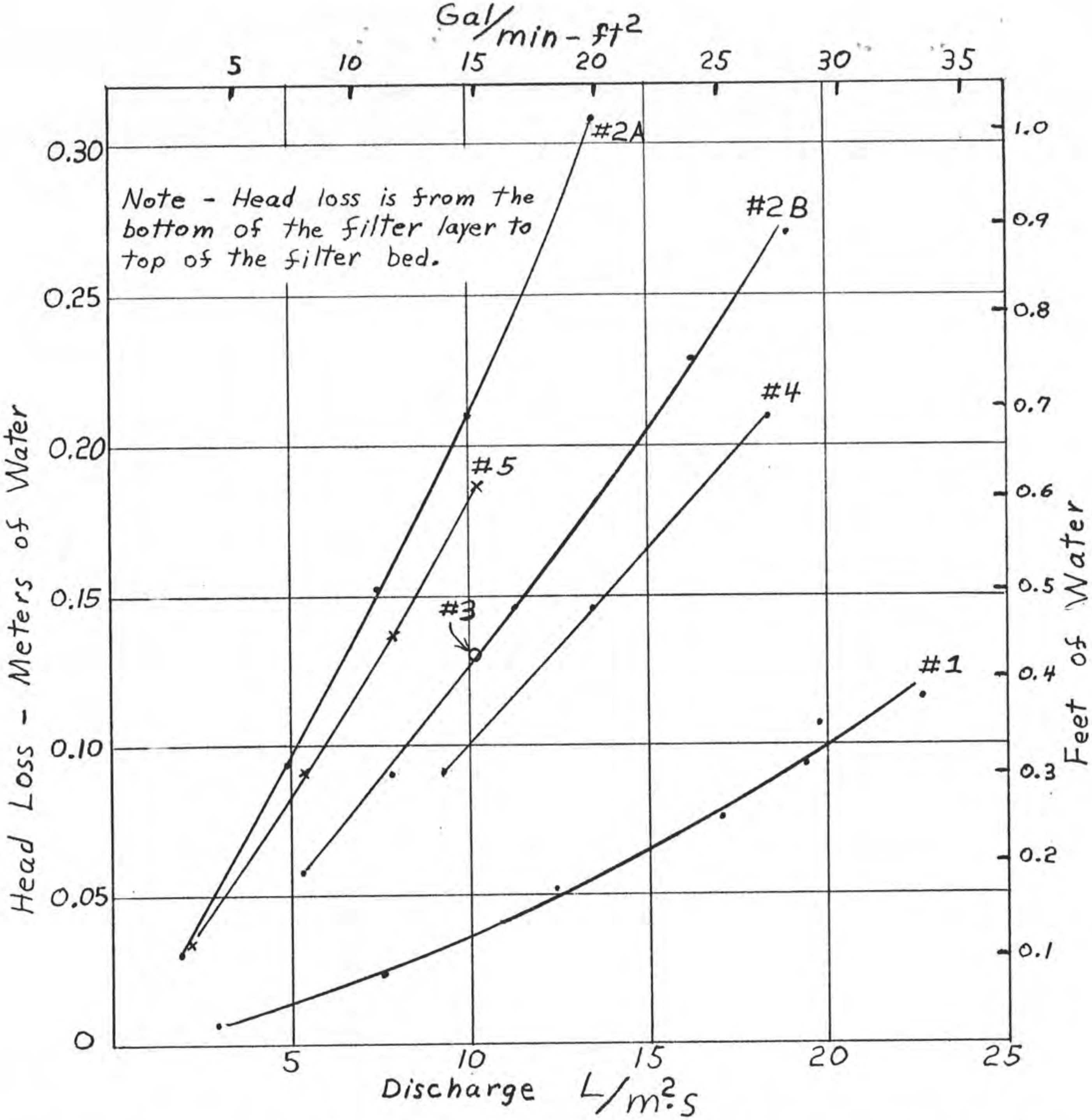


Figure 4 - Filtration tests for clean filter bed condition

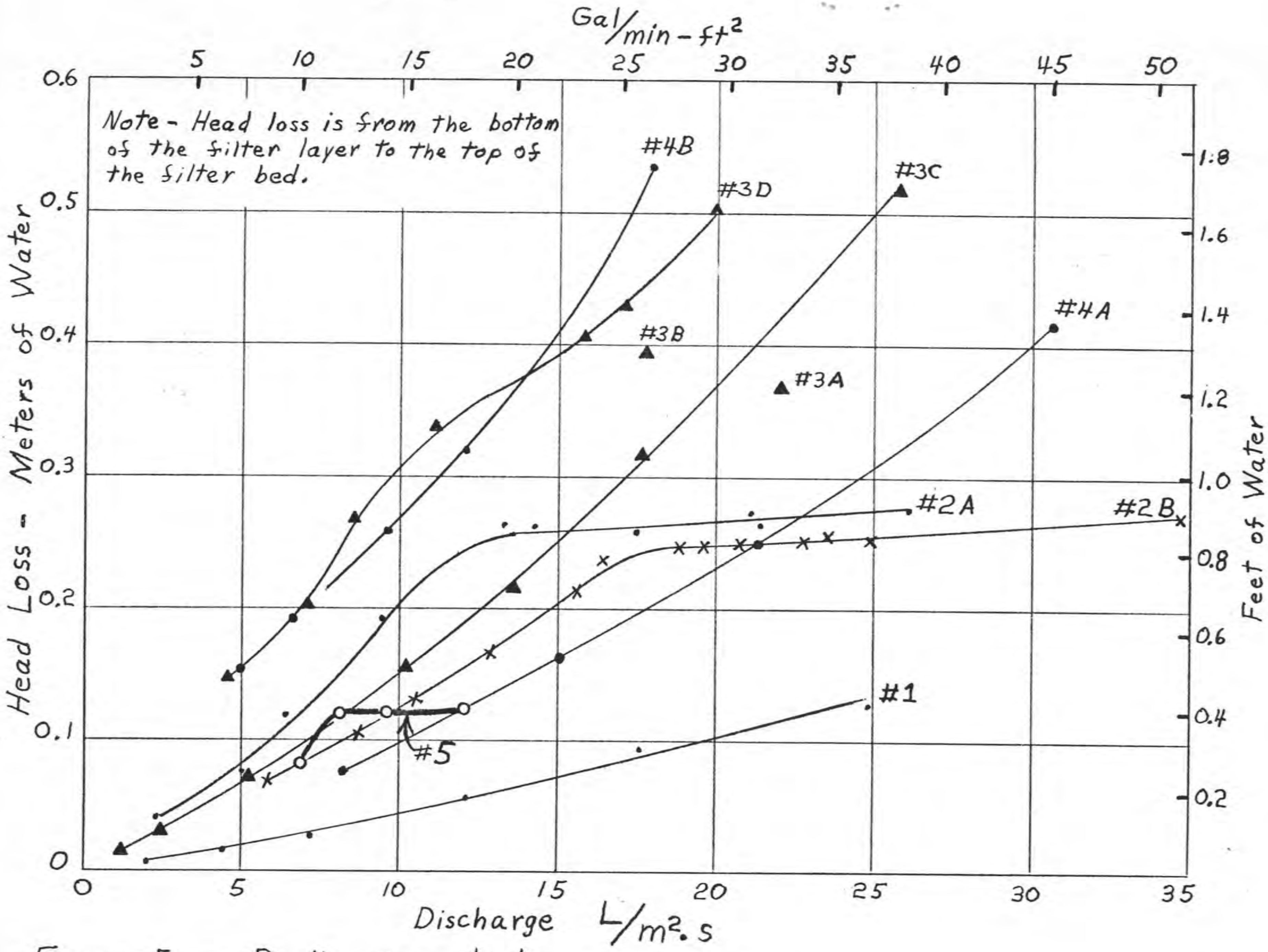
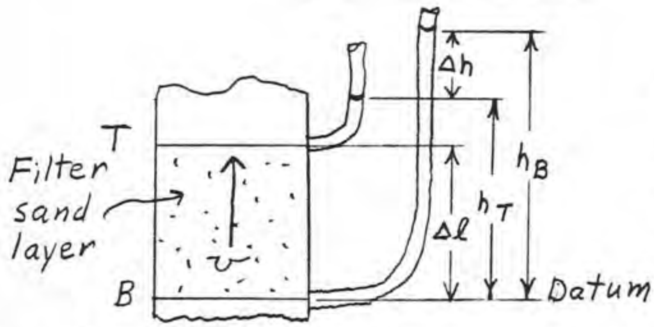


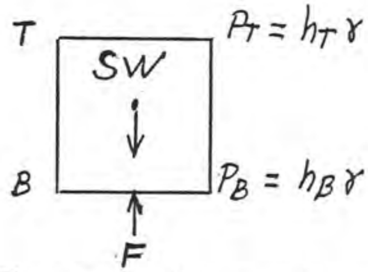
Figure 5. - Backwashing tests



(a) Resistance of flow through filter sand layer.

$$v = Ki = K \frac{\Delta h}{\Delta \ell}$$

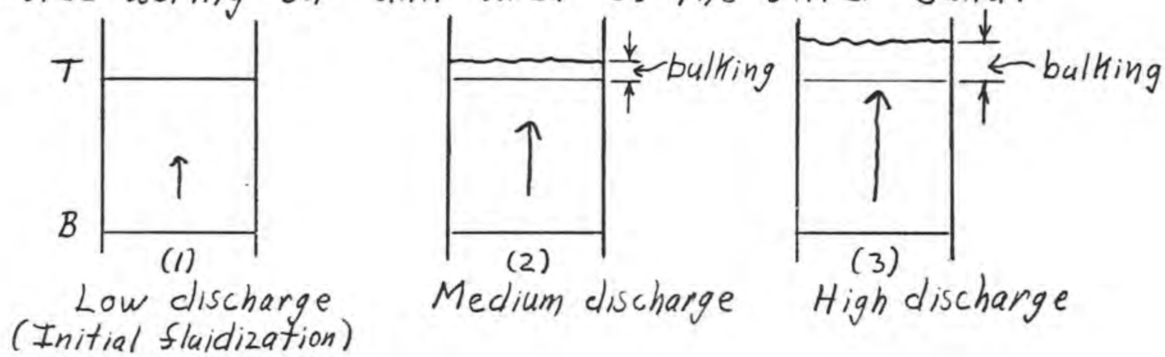
v - velocity
K - coefficient of permeability
i - hydraulic gradient
Δh - head loss
$\Delta \ell$ - length over which head loss occurs
h - piezometric head
γ - specific weight water
P - pressure
A - unit area
SW - submerged weight
F - force



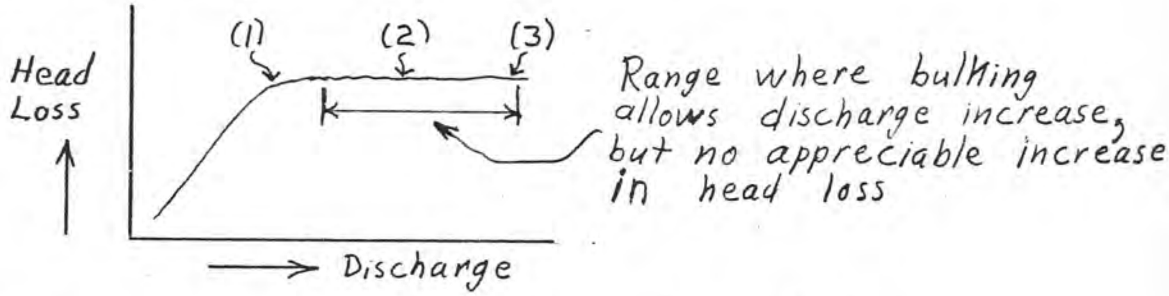
$$F = PA$$

$$F = (P_T - P_B)A = \Delta h \gamma A$$

(b) Force acting on unit area of the filter sand.

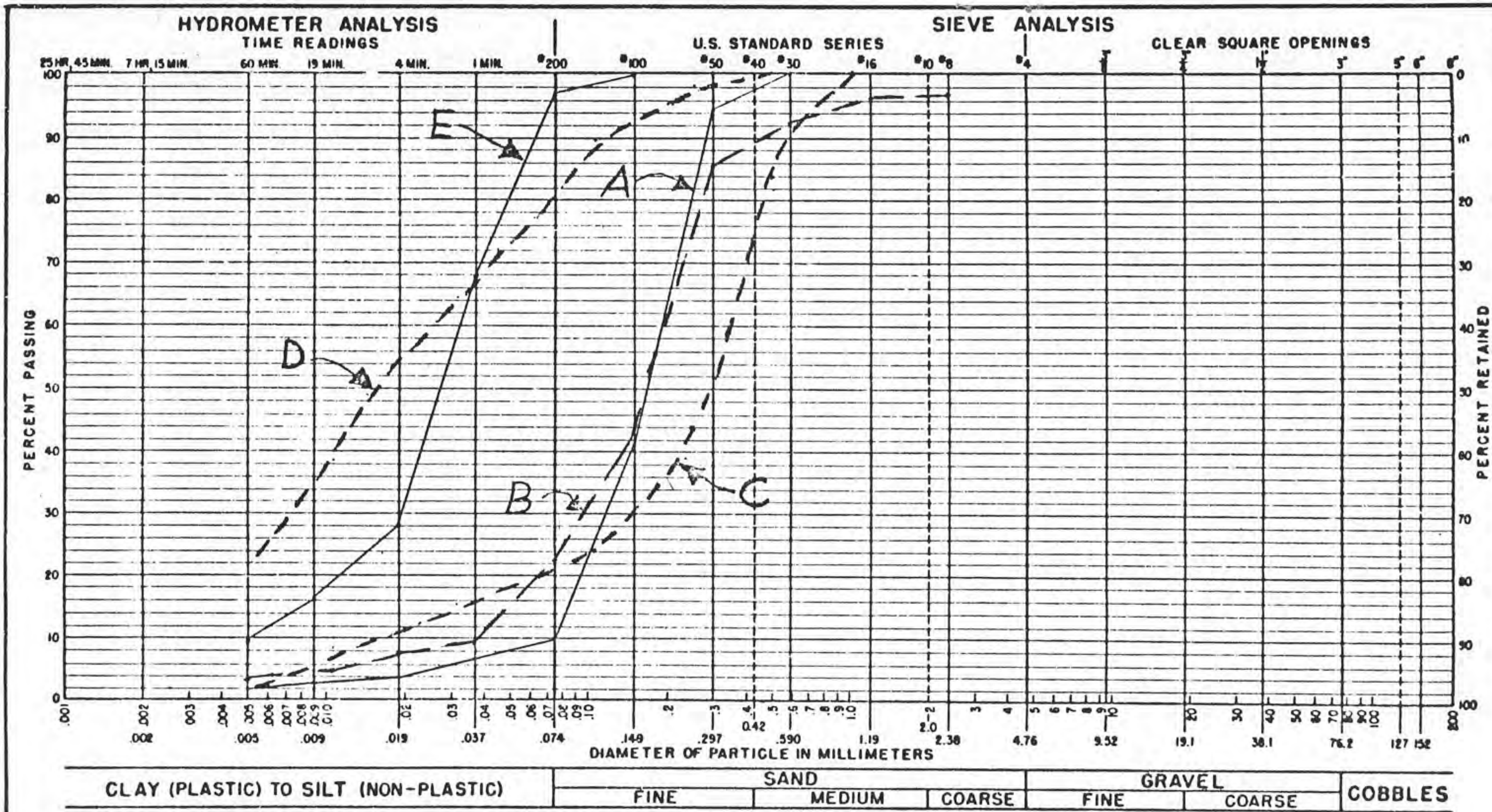


(c) Effect of discharge upon the sand bed



(d) Relationship between discharge and head loss.

Figure 6. - Fluidization



NOTES: A - First sediment used in lab tests

GRADATION TEST

B - Sediment received from the Okanogan River

C&D - Suspended sediment samples taken June 1978, Okanogan River

E - Sediment that can be used in future lab tests

Figure 7. - Sediment size.

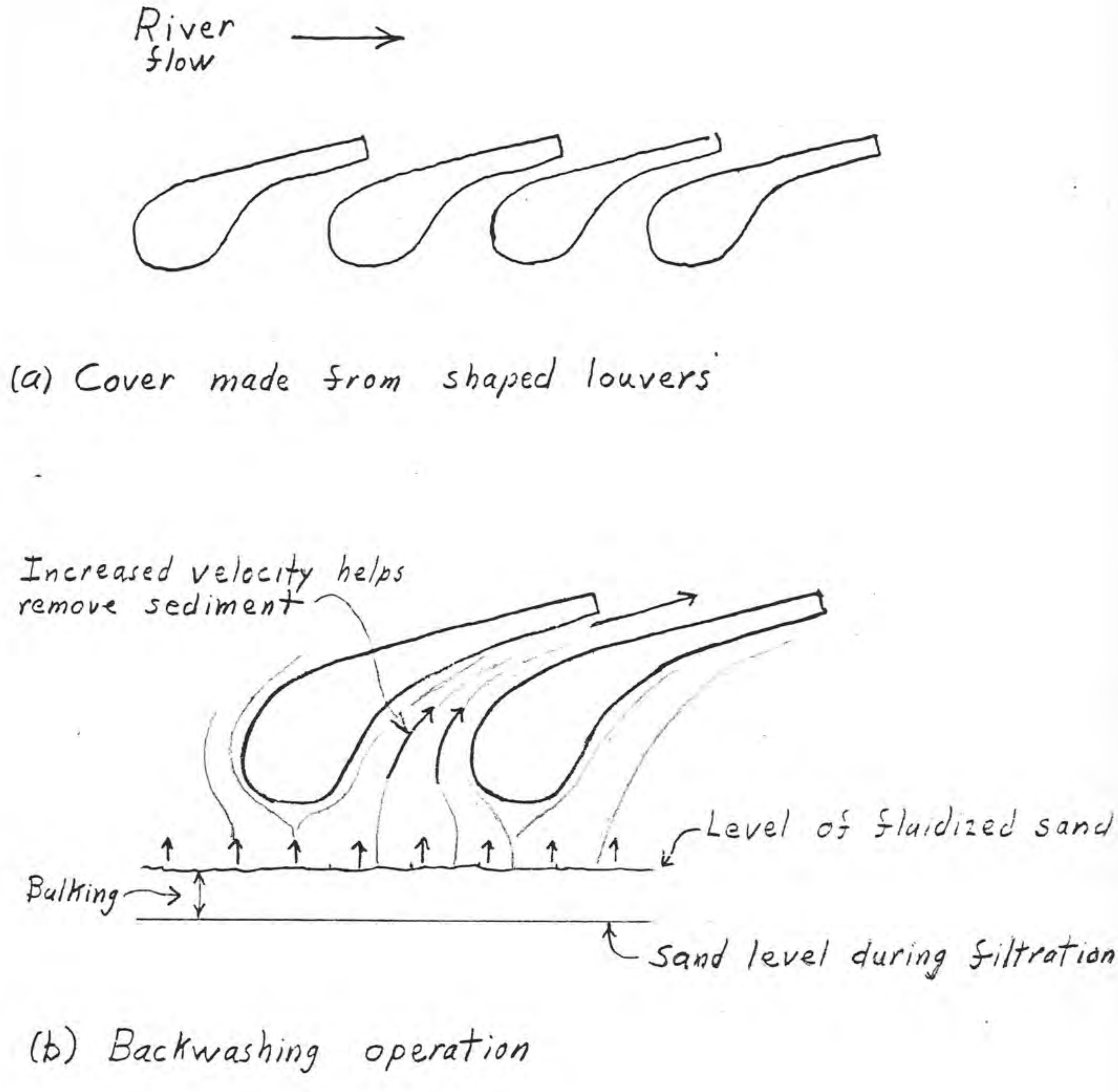


Figure 8.- Concept of cover to protect filter sand from river currents.